N92-24331

ALTERNATIVE METHODS TO MODEL FRICTIONAL CONTACT SURFACES USING NASTRAN

Joseph Hoang

GE Goverment Services, Houston, Texas

SUMMARY

Elongated (slotted) holes have been used extensively for the integration of equipment into Spacelab racks. In the past, this type of interface has been modelled assuming that (i) there is no slippage between contact surfaces, or (ii) there is no load transfer in the direction of the slot. Since the contact surfaces are bolted together, the contact friction provides a load path determined by the normal applied force (bolt preload) and the coefficient of friction. This paper examines three alternate methods that utilize spring elements, externally applied couples, and stress dependent elements to model the contacted surfaces. Results of these methods are compared with results obtained from methods that use GAP elements and rigid elements.

INTRODUCTION

Elongated holes have been used in the design of Spacelab Experiment Equipment mounting provisions. This type of joint is employed where large tolerances are allowed in one direction of the hole for the ease of integration. A simple way to model these interfaces is to use RIGID elements with the assumption that two connecting grid points are not moving against each other when loads are applied. Another common method is to use RIGID elements with the degrees of freedom associated with the longitudinal direction of the elongated hole released. When using this method, it is assumed that the joint did not carry load in its slotted direction.

Due to the assumption involved, neither method yields realistic results. GAP elements have been used to achieve better results. However, when large numbers of GAP elements are used in a complex model, an unreasonably large amount of computer processing time is required to solve the system and, hence, is not economical or practical.

In this paper, three alternative methods are investigated. The first method employs a spring element with a spring rate equal to the maximum load at the connection divided by the gap length. By using a spring element at the connection, the nonlinear frictional force developed at the gap is replaced by a spring force that increases proportionally with gap distance. The second method used an externally applied couple to represent the frictional forces at the two contacted surfaces. This method creates a local realization of frictional forces when two grid points, representing two contacted surfaces, move against each other. In the third method, two contacted surfaces are connected by elements with stress-dependent material properties. The piecewise linear static analysis rigid format is ultilized to solve element forces at these elements.

A simple stowage container and four supporting columns were developed to represent a typical installation in a Spacelab rack. The container was integrated on supporting columns using the above methods. The models were run on a SUN workstation using CSA/NASTRAN. The results obtained from each method were then compared.

THEORY AND BACKGROUND

Figure 1a shows a typical elongated hole and Figure 1b shows force vs. relative displacement of an elongated hole. The force vs. displacement curves of other elements are shown in Figures 2 through 7.

From inspection, the stress dependent material element is the more appropriate element to simulate elongated hole behavior because the GAP element, spring element and coupled element would generate some error. A rigid element with all three translational degrees of freedom coupled (R123) should be used only when the frictional force is greater than the force at the connection. A rigid element with degrees of freedom associated with the longitudinal direction of the hole released (R23) should be used when, the frictional force and the displacement in elongated direction are small.

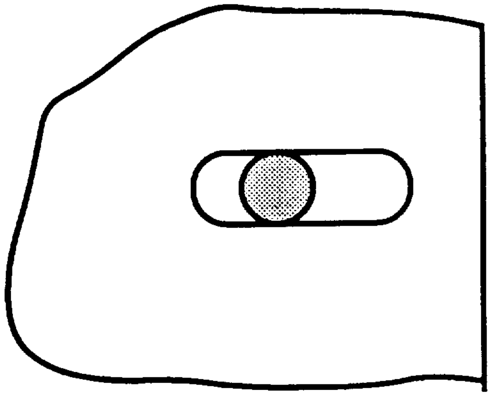

Fig. 1a Typical elongated hole

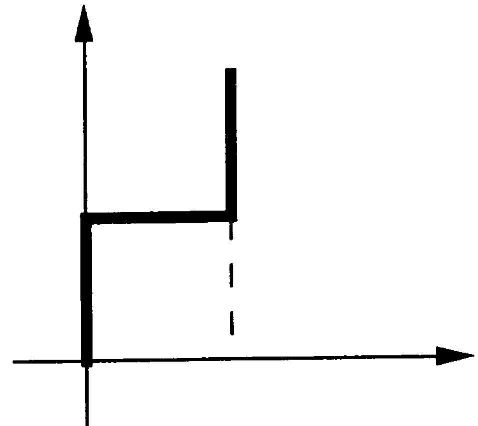

Fig. 1b Force vs. displacement of elongated hole

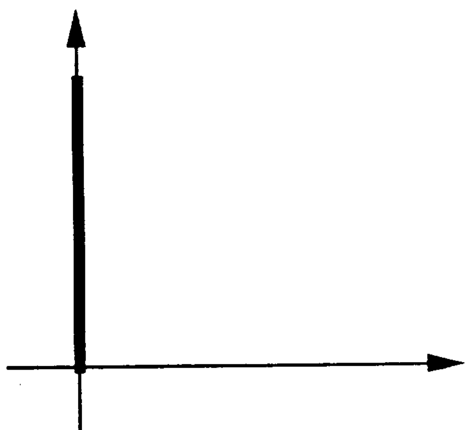

Fig. 2 Force vs. displacement of R123 element

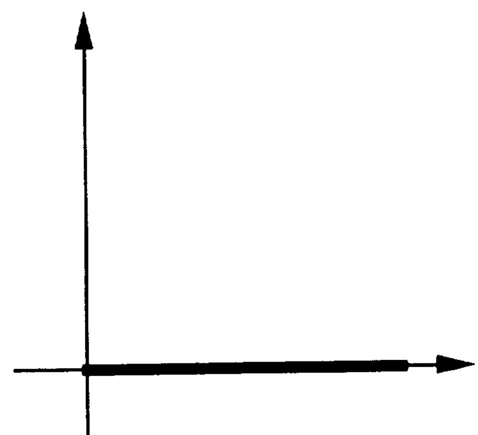

Fig. 3 Force vs. displacement of R23 element

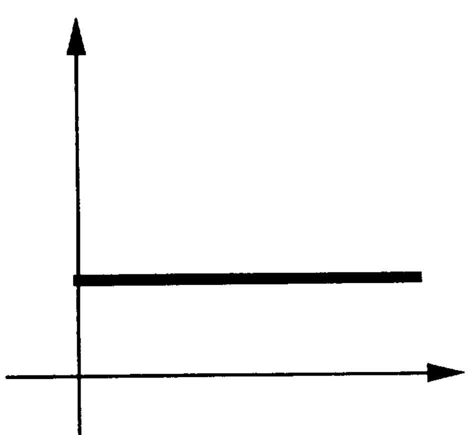

Fig. 4 Force vs. displacement of "couple" element

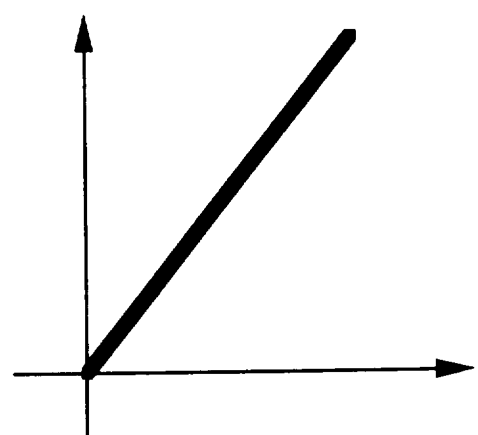

Fig. 5 Force vs. displacement of spring element

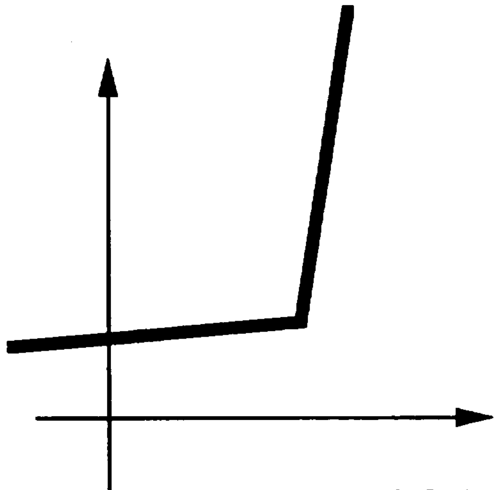

Fig. 6 Force vs. displacement of GAP element

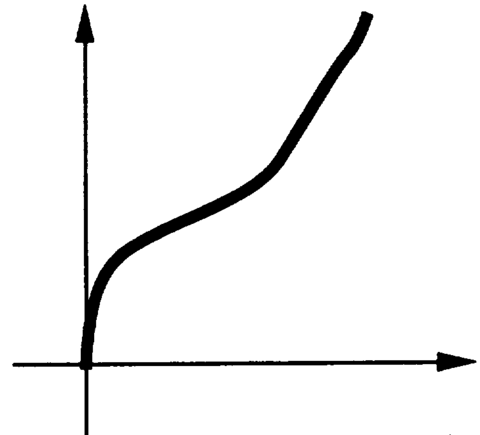

Fig. 7 Force vs. displacement of nonlinear element

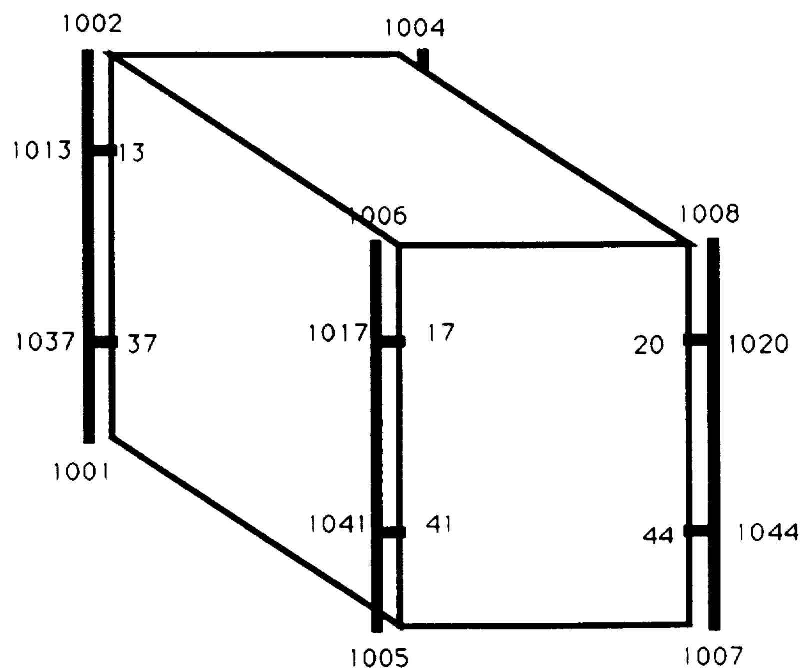

Fig. 8 Plot of test subject: a simple box and four supported columns

ANALYSIS AND RESULTS

A simple box is constructed using QUAD2 elements. It is supported by four columns which were modelled using BAR elements. A plot of the structure is shown in Figure 8. In the rear, the box is mounted on two rear columns at grid points 13, 24, 37, and 48 using rigid elements with all three translational degrees of freedom coupled. In front, the box is mounted to the front left column at grid points 17 and 41 and to the front right column at grid points 20, and 44, using a different integrating method. Gravitational loads varying from 0.2g to 4.0g are applied to the model in the X-direction, which is parallel to the slotted direction.

The material and properties of QUAD2 and BAR elements are chosen such that the box is heavier and more flexible than the columns. Since the columns are much stiffer than the box, displacement of the grid point on the column is small as compared to displacement of the grid point on the box. Displacement of the rear panel is closed to the displacement of rear columns because the rear panel interface points are mounted to the rear columns by rigid elements with all three translational degrees of freedom coupled. However, at the front panel, the relative displacement of front panel and front columns are greatly dependent on the type of connecting elements used. It should also be noted that the single point constraint forces developed at the front columns are also dependent on the amount of load that has been transfered to the columns through the front connecting elements.

Properties of each type of connecting element are chosen in such a way that its deformation can follow the elongated hole displacement curve as close as possible. The gap length and frictional force of the contacting surface were chosen arbitrarily at 0.5 inches and 15.0 lbs respectively.

Displacement of the left front interfaces (grid points 17 and 41 were identical and were tabulated in Table 1). The single point constraint force of the left front column (grid points 1005 and 1006) are tabulated in Table 2. Table 3 shows the displacement of the right front interfaces (grid points 20, and 44) while Table 4 shows a single point constraint force of the right front column (grid points 1007 and 1008).

TABLE 1 DISPLACEMENT VECTOR OF GRID POINT 17 AND 41
LEFT FRONT COLUME

LOAD G	R123 in	R23 in	COUPLE in	SPRING in	NONLINEAR in	GAP in
0.2	4.609476E-05	1.919124E-01	-1.049302E+00	7.230263E-02	2.630225E-04	2.693819E-01
0.4	9.218953E-05	3.838249E-01	-8.573890E-01	1.446053E-01	7.430014E-04	5.000591E-01
0.6	1.382843E-04	5.757374E-01	-6.654766E-01	2.169079E-01	1.222980E-03	5.002077E-01
0.8	1.843791E-04	7.676498E-01	-4.735641E-01	2.892105E-01	1.702959E-03	5.003563E-01
1.0	2.304738E-04	9.595622E-01	-2.816517E-01	3.615132E-01	2.182937E-03	5.005049E-01
1.2	2.765686E-04	1.151475E+00	-8.973924E-02	4.338158E-01	2.662916E-03	5.006534E-01
1.4	3.226633E-04	1.343387E+00	1.021732E-01	5.061184E-01	1.419462E-01	5.008020E-01
1.6	3.687581E-04	1.535300E+00	2.940856E-01	5.784211E-01	4.199264E-01	5.009505E-01
1.8	4.148529E-04	1.727212E+00	4.859981E-01	6.507237E-01	5.594884E-01	5.010991E-01
2.0	4.609476E-04	1.919124E+00	6.779105E-01	7.230263E-01	5.599684E-01	5.012476E-01
2.2	5.070424E-04	2.111037E+00	8.698230E-01	7.953290E-01	5.604484E-01	5.013962E-01
2.4	5.531372E-04	2.302949E+00	1.061735E+00	8.676316E-01	5.609283E-01	5.015448E-01
2.6	5.992319E-04	2.494862E+00	1.253648E+00	9.399343E-01	5.614084E-01	5.016934E-01
2.8	6.453267E-04	2.686774E+00	1.445560E+00	1.012237E+00	5.618884E-01	5.018419E-01
3.0	6.914214E-04	2.878687E+00	1.637473E+00	1.084540E+00	5.623684E-01	5.019905E-01
3.2	7.375162E-04	3.070599E+00	1.829385E+00	1.156842E+00	5.628484E-01	5.021390E-01
3.4	7.836110E-04	3.262512E+00	2.021298E+00	1.229145E+00	5.633284E-01	5.022876E-01
3.6	8.297057E-04	3.454424E+00	2.213210E+00	1.301447E+00	5.638084E-01	5.024362E-01
3.8	8.758005E-04	3.646336E+00	2.405123E+00	1.373750E+00	5.642884E-01	5.025848E-01
4.0	9.218953E-04	3.838249E+00	2.597035E+00	1.446053E+00	5.647684E-01	5.027333E-01

TABLE 2 FORCES OF SINGLE-POINT CONSTRAINT GRID POINT 1005 AND 1006
LEFT FRONT COLUME

LOAD G	R123 Lbs	R23 Lbs	COUPLE Lbs	SPRING Lbs	NONLINEAR Lbs	GAP Lbs
0.2	-2.480673E+00	-1.619789E-01	-1.516198E+01	-1.607457E+00	-2.415121E+00	-4.313539E-01
0.4	-4.961346E+00	-3.239577E-01	-1.532396E+01	-3.214913E+00	-4.775031E+00	-1.135344E+00
0.6	-7.442019E+00	-4.859366E-01	-1.548594E+01	-4.822370E+00	-7.134942E+00	-3.463185E+00
0.8	-9.922691E+00	-6.479155E-01	-1.564791E+01	-6.429826E+00	-9.494853E+00	-5.791025E+00
1.0	-1.240336E+01	-8.098943E-01	-1.580989E+01	-8.037283E+00	-1.185476E+01	-8.118866E+00
1.2	-1.488404E+01	-9.718732E-01	-1.597187E+01	-9.644740E+00	-1.421467E+01	-1.044671E+01
1.4	-1.736471E+01	-1.133852E+00	-1.613385E+01	-1.125220E+01	-1.553790E+01	-1.277455E+01
1.6	-1.984538E+01	-1.295831E+00	-1.629583E+01	-1.285965E+01	-1.592276E+01	-1.510239E+01
1.8	-2.232606E+01	-1.457810E+00	-1.645781E+01	-1.446711E+01	-1.729169E+01	-1.743023E+01
2.0	-2.480673E+01	-1.619789E+00	-1.661979E+01	-1.607457E+01	-1.965161E+01	-1.975807E+01
2.2	-2.728740E+01	-1.781768E+00	-1.678177E+01	-1.768202E+01	-2.201151E+01	-2.208591E+01
2.4	-2.976807E+01	-1.943746E+00	-1.694375E+01	-1.928948E+01	-2.437144E+01	-2.441375E+01
2.6	-3.224874E+01	-2.105725E+00	-1.710573E+01	-2.089693E+01	-2.673135E+01	-2.674159E+01
2.8	-3.472942E+01	-2.267704E+00	-1.726771E+01	-2.250439E+01	-2.909127E+01	-2.906943E+01
3.0	-3.721009E+01	-2.429683E+00	-1.742968E+01	-2.411185E+01	-3.145117E+01	-3.139727E+01
3.2	-3.969077E+01	-2.591662E+00	-1.759166E+01	-2.571931E+01	-3.381108E+01	-3.372511E+01
3.4	-4.217144E+01	-2.753641E+00	-1.775364E+01	-2.732676E+01	-3.617098E+01	-3.605296E+01
3.6	-4.465211E+01	-2.915620E+00	-1.791562E+01	-2.893422E+01	-3.853089E+01	-3.838079E+01
3.8	-4.713278E+01	-3.077598E+00	-1.807760E+01	-3.054168E+01	-4.089083E+01	-4.070864E+01
4.0	-4.961346E+01	-3.239577E+00	-1.823958E+01	-3.214913E+01	-4.325074E+01	-4.303648E+01

TABLE 3 DISPLACEMENT VECTOR OF GRID POINT 20 AND 44
RIGHT FRONT COLUME

LOAD G	R123 in	R23 in	COUPLE in	SPRING in	NONLINEAR in	GAP in
0.2	4.609476E-05	1.919124E-01	-1.049302E+00	7.230263E-02	2.569049E-04	2.693819E-01
0.4	9.218953E-05	3.838249E-01	-8.573890E-01	1.446053E-01	7.286069E-04	5.000591E-01
0.6	1.382843E-04	5.757374E-01	-6.654766E-01	2.169079E-01	1.200309E-03	5.002077E-01
0.8	1.843791E-04	7.676498E-01	-4.735641E-01	2.892105E-01	1.672011E-03	5.003563E-01
1.0	2.304738E-04	9.595622E-01	-2.816517E-01	3.615132E-01	2.143713E-03	5.005049E-01
1.2	2.765686E-04	1.151475E+00	-8.973924E-02	4.338158E-01	2.615415E-03	5.006534E-01
1.4	3.226633E-04	1.343387E+00	1.021732E-01	5.061184E-01	1.416968E-01	5.008020E-01
1.6	3.687581E-04	1.535300E+00	2.940856E-01	5.784211E-01	4.196053E-01	5.009505E-01
1.8	4.148529E-04	1.727212E+00	4.859981E-01	6.507237E-01	5.591255E-01	5.010991E-01
2.0	4.609476E-04	1.919124E+00	6.779105E-01	7.230263E-01	5.595973E-01	5.012476E-01
2.2	5.070424E-04	2.111037E+00	8.698230E-01	7.953290E-01	5.600690E-01	5.013962E-01
2.4	5.531372E-04	2.302949E+00	1.061735E+00	8.676316E-01	5.605407E-01	5.015448E-01
2.6	5.992319E-04	2.494862E+00	1.253648E+00	9.399343E-01	5.610124E-01	5.016934E-01
2.8	6.453267E-04	2.686774E+00	1.445560E+00	1.012237E+00	5.614842E-01	5.018419E-01
3.0	6.914214E-04	2.878687E+00	1.637473E+00	1.084540E+00	5.619559E-01	5.019905E-01
3.2	7.375162E-04	3.070599E+00	1.829385E+00	1.156842E+00	5.624276E-01	5.021390E-01
3.4	7.836110E-04	3.262512E+00	2.021298E+00	1.229145E+00	5.628994E-01	5.022876E-01
3.6	8.297057E-04	3.454424E+00	2.213210E+00	1.301447E+00	5.633711E-01	5.024362E-01
3.8	8.758005E-04	3.646336E+00	2.405123E+00	1.373750E+00	5.638429E-01	5.025848E-01
4.0	9.218953E-04	3.838249E+00	2.597035E+00	1.446053E+00	5.643146E-01	5.027333E-01

TABLE 4 FORCES OF SINGLE-POINT CONSTRAINT GRID POINT 1007 AND 1008
RIGHT FRONT COLUME

LOAD G	R123 Lbs	R23 Lbs	COUPLE Lbs	SPRING Lbs	NONLINEAR Lbs	GAP Lbs
0.2	-2.480673E+00	-1.619789E-01	-1.516198E+01	-1.607457E+00	-2.391965E+00	-4.313539E-01
0.4	-4.961346E+00	-3.239577E-01	-1.532396E+01	-3.2[illegible]4913E+00	-4.713940E+00	-1.135344E+00
0.6	-7.442019E+00	-4.859366E-01	-1.548594E+01	-4.8[illegible]2370E+00	-7.035915E+00	-3.463185E+00
0.8	-9.922691E+00	-6.479155E-01	-1.564791E+01	-6.4[illegible]9826E+00	-9.357891E+00	-5.791025E+00
1.0	-1.240336E+01	-8.098943E-01	-1.580989E+01	-8.0[illegible]7283E+00	-1.167987E+01	-8.118866E+00
1.2	-1.488404E+01	-9.718732E-01	-1.597187E+01	-9.6[illegible]4740E+00	-1.400184E+01	-1.044671E+01
1.4	-1.736471E+01	-1.133852E+00	-1.613385E+01	-1.1[illegible]5220E+01	-1.540400E+01	-1.277455E+01
1.6	-1.984538E+01	-1.295831E+00	-1.629583E+01	-1.285965E+01	-1.578881E+01	-1.510239E+01
1.8	-2.232606E+01	-1.457810E+00	-1.645781E+01	-1.446711E+01	-1.713961E+01	-1.743023E+01
2.0	-2.480673E+01	-1.619789E+00	-1.661979E+01	-1.607457E+01	-1.946158E+01	-1.975807E+01
2.2	-2.728740E+01	-1.781768E+00	-1.678177E+01	-1.768202E+01	-2.178356E+01	-2.208591E+01
2.4	-2.976807E+01	-1.943746E+00	-1.694375E+01	-1.928948E+01	-2.410551E+01	-2.441375E+01
2.6	-3.224874E+01	-2.105725E+00	-1.710573E+01	-2.089693E+01	-2.642749E+01	-2.674159E+01
2.8	-3.472942E+01	-2.267704E+00	-1.726771E+01	-2.250439E+01	-2.874946E+01	-2.906943E+01
3.0	-3.721009E+01	-2.429683E+00	-1.742968E+01	-2.411185E+01	-3.107145E+01	-3.139727E+01
3.2	-3.969077E+01	-2.591662E+00	-1.759166E+01	-2.571931E+01	-3.339342E+01	-3.372511E+01
3.4	-4.217144E+01	-2.753641E+00	-1.775364E+01	-2.732676E+01	-3.571540E+01	-3.605296E+01
3.6	-4.465211E+01	-2.915620E+00	-1.791562E+01	-2.893422E+01	-3.803738E+01	-3.838079E+01
3.8	-4.713278E+01	-3.077598E+00	-1.807760E+01	-3.054168E+01	-4.035932E+01	-4.070864E+01
4.0	-4.961346E+01	-3.239577E+00	-1.823958E+01	-3.214913E+01	-4.268130E+01	-4.303648E+01

DISCUSION

Examination of the displacement of the left and right front panels of the box and the load distribution over four supporting columns indicates that types R123 and R23 are the two extreme cases. For rigid R123 types, the load was distributed evenly over four columns; meanwhile, for rigid R23 types, the load was carried by the rear columns only, and the box acts as a cantilever beam. The exact load distribution pattern is somewhere between the boundary established by these two types of connections. With finer load increments, the displacement curve of a stress dependent material element can be made to match the displacement curve of an elongated hole and, therefore, used as a reference to evaluate performance of other types of connections.

In general, static analysis with GAP elements and piecewise linear analysis employ an iterative scheme for solution. They are costly to run especially when models become complex. For the problem at hand, the GAP element did not yield a corrected solution when under tension load, meanwhile, stress dependent material elements did not perform well when under compression. Therefore, these two types of elements were not suitable for a model with multiple loading cases where the directions of the load at the interfaces are often unknown.

A *couple* type connection shows the same characteristics as the R23 type, with the displacement shifted due to externally applied couple. It is also difficult to use when the direction of the loads at the connection is unknown. However, the solution can be obtained with less computing time.

The solution for rigid elements and spring elements always contains some degree of error, but can be obtained with less computing time, and can be used in problems involving multiple loading conditions. The spring rate can be adjusted to control the relative displacement of the two connecting grid points.

RECOMMENDATION

It is recommended that for problems with multiple loading conditions, models should be run first using R123 type connections. Then, for interfaces that develop forces larger than the frictional forces of the elongated hole, the type R123 connection should be replaced with appropriate spring elements. This methodology yields reasonable results with minimum computer run time.